PATENT SPECIFICATION

686,375

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COMPLETE SPECIFICATION

Improvements in or relating to a Process and Apparatus for Evaporating Liquids

I, ARTHUR HAROLD STEVENS, a British Subject, of the Firm of Stevens, Langner Parry & Rollinson, Chartered Patent Agents, of 5—9, Quality Court, Chancery Lane, London, W.C.2, do hereby declare the nature of this invention (communication from Mojonnier Bros., Co., a Corporation organised under the laws of the State of Illinois, United States of America, of 4601, West Ohio Street, Chicago, State of Illinois, United States of America), and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to a process and apparatus for evaporating liquids at temperatures lower than the boiling points at atmospheric pressure and relates particularly to a process and apparatus that are suitable and especially adapted for the concentration of solutions containing heat sensitive materials whereby evaporation at low temperature ranges is desirable.

The invention relates to a process for evaporating an aqueous solution under vacuum comprising effecting heat exchange between a compressed refrigerant gas and the solution to vaporize water from the solution and liquefy the gas, cooling the liquified refrigerant to a temperature lower than that of the water vapor evaporated from the solution, effecting heat exchange between the cooled refrigerant and the water vapor to vaporize the refrigerant and condense the water vapor thereby imposing a vacuum on the solution, re-compressing the vaporized refrigerant for re-use in boiling further solution, and characterized by discharging continuously from the process sufficient of the heat which otherwise would be re-cycled in the refrigerant to maintain a substantially constant compressor output pressure.

The system is designed and constructed for continuous operation. As contrasted to most evaporation processes, the present invention requires little fuel. A moderate amount of power is required for operating the refrigerant compressor, and only a relatively small amount of water or other coolant is required for accomplishing a desired cooling of the refrigerant.

In the drawings is shown, for illustrative purposes, a preferred embodiment of the apparatus of the invention and this will be described as it is used for the evaporation of heat sensitive materials, for example, citrus fruit juices and among them orange juice. The latter is mentioned because of the great utility of the invention as applied to the concentration of this particular product.

While various refrigerants may be used, ammonia has been used particularly and the temperatures and pressures given herein refer to ammonia.

In the drawings:

Figure 1 is a diagrammatic layout of an apparatus by means of which the invention may be practised;

Figure 2 is an end view of the apparatus shown in Figure 1;

Figure 3 is a top plan view of the apparatus shown in Figure 1;

Figure 4 is an enlarged partial sectional view of the upper end of one of the evaporators;

Figure 5 is a vertical sectional view of the lower end of one of the evaporators, on line V—V of Figure 1;

Figure 6 is a sectional view on the line VI—VI of Figure 2;

Figure 7 is an elevation of a condenser.

The apparatus includes an evaporator into which a hot compressed refrigerant gas is introduced to supply heat for boiling the liquid to be concentrated, and a condenser in which the low temperature water vapors from the evaporator are condensed during heat exchange with the liquified refrigerant which at that time vaporizes into a gas.

While various forms of heat exchangers may be employed, there has been selected for disclosure herein a series of connected falling film type evaporator units, each unit including a vertical tubular evaporator having a shell 11, see Figs. 1 to 5, and a nest of tubes 12 which are retained in the upper and lower tube sheets 13 and 14.

The compressed hot refrigerant gas is introduced into each evaporator through a pipe 15, see Figs. 2 to 4, and circulates around the outside of the tubes 12, being withdrawn, principally as a condensate through a bottom

outlet pipe 16. The inlet pipes 15 for the refrigerant gas are connected to a common supply pipe 17.

As indicated in Figure 4, the upper ends of the tubes 12 are fixed in the upper tube sheet 13. It is intended that the space above the upper tube sheet will be kept flooded with the orange juice and in order to regulate the flow of juice into these tubes and downwardly, there has been inserted in each tube 12 a removable tube 18 which is supported centrally in the top of the tube by a bracket in the form of a spider 19 having three or more legs which rest upon the top of the tube sheet, the legs being secured by welding or in any other suitable manner to the tubes 18 to support them in an upright position.

It will be noted that the lower end of each tube 18 is flared outwardly as shown at 20 to retard the flow of the orange juice past that area and to cause it to positively come into contact with the inner walls of the tubes 12. The supply of orange juice which is caused to flow downwardly through these tubes is brought to the top of each evaporator by means of a pipe 21. It is apparent that the layer of juice above the tube sheet may be varied in depth, the greater the depth, the greater the rate of flow past the flared lower end of the regulating tubes 18. Since these tubes are readily removable along with their supporting spiders, cleaning of the upper end of the evaporator and the vertical tubes is facilitated.

As indicated in Figures 2 and 5, the lower ends of the tubes 12 open directly into a curved hood 22 which will serve to conduct the vapors and the unvaporized juice from the lower ends of the tubes. The liquid will flow into a sump 23 while the vapor will be drawn into a cylindrical chamber 24 and evacuated therefrom through a central aperture 25 and an outlet pipe 26 into the condensing unit.

The evaporator unit shown in Figures 1 and 3 consists of three vertical tubular evaporators of substantially identical construction, all supplied with the hot refrigerant gas by the common supply pipe 17 and interconnected at their lower ends through the communicating drums 24, shown in section in Figure 6.

The sumps 23 are interconnected as shown in Figs. 1 and 6 by the pipes 28 and 29, to permit flow of a juice from the first sump to the next one to the right thereof, and from the second to the third sump, after which the concentrated juice is withdrawn through an outlet pipe 30 by a pump 31, from the system.

Connected with the bottoms of the sumps are the pipes 32, each of which leads to a pump 33 for recirculating juice back again to the top of the same evaporator from which it is withdrawn, that is through the pipes 21. It is intended that, in the use of these falling film evaporators, rapid recirculation pumps will be provided which will keep a constant supply of liquid above the top tube sheet in each evaporator and return to the top of each evaporator whatever liquid passes downwardly through the tubes without having become evaporated. In the meantime any vapor escaping from the juice within the tubes is drawn downwardly and passes into the drums 24 with a whirling motion which serves to throw entrained particles, if any, centrifugally against the outer walls of the drums, to thus free the vapor of droplets before it is evacuated through the central opening 25 and the vapor outlet pipe 26. It will be noted that the central openings 25 are formed by means of the inturned end flanges of the individual drums 24, these flanges being readily riveted or welded together, but having the large central openings indicated.

Each chamber 24 preferably will have an arcuate baffle 24^1 secured to the margin of opening 25 which will assist in imparting centrifugal motion about a horizontal axis to the vapors and prevent their more direct flow through ports 25.

The fresh dilute juice is supplied to the system of evaporators from a de-aerator (to be described later) through a pipe 34, see Fig. 1, connected to the downflow pipe 32 in the first evaporator. Each evaporator unit therefore performs a substantial portion of the total evaporation job, and because of the action of the outflow pump 31, there will be a continuous flow of juice from the first evaporator successively through the others to the last. The first evaporator, because it contains the most dilute juice, will evaporate the largest number of pounds of water per hour. Evaporation from the succeeding evaporators will be at a lower rate per hour and in the final evaporator the evaporation will continue at the lowest rate of evaporation until the desired density has been attained. A sight glass 23^1 on each sump, as in Figure 5, will facilitate maintaining adequate levels in the units.

The water vapor evacuated from the evaporators through the pipe 26 is conducted to a large tubular condenser 35, the vapor surrounding the tubes while evaporation of the liquid refrigerant within the tubes will cause condensation of the water vapor. The water vapor condensate will be withdrawn by a pipe 36 into a tank 37 and pumped therefrom by a condensate pump 38. The sight glass 37^1 will enable the operator to make certain that the pump is always primed.

As there may be some uncondensable gases such as air in the water vapor, these gases

will be withdrawn from the condenser 35 through a pipe 39 by an ejector 40, of any suitable design.

Under the pressure maintained on the refrigerant gas in the evaporators, most of this gas will become condensed to a liquid state, the latent heat of liquefaction of the refrigerant being transferred to the boiling juices. The refrigerant is withdrawn from each tube chest through a pipe 16, see Fig. 5, into a common header 41, see Figs. 1 and 3, thence through a water cooled condenser 42, pipe 42[1] and a liquid refrigerant cooler 43. Cooling water for the cooler and condenser are supplied by a pump 44 to the cooler 43 and through the interconnecting pipe 45 to the condenser 42, and is discharged through an outlet pipe 46.

The liquid refrigerant then flows through pipe 47 to a receiver 48, Fig. 1. If desired the admission of the liquid refrigerant into the receiver 48 may be controlled by a float valve 49, although it may be controlled by some other valve which will serve to maintain pressure on the high pressure side of the system.

Liquid refrigerant from the receiver 48 is conducted through a pipe 50 to the bottom of the tubular evaporator 35, which is preferably of a common tubular chest construction, and allowed to flow upwardly through the vertical tubes therein which are sufficiently indicated by partial sectional view of the evaporator. The evaporator 35 is referred to hereinafter in the claims as a condenser, in view of its important function of condensing the water vapor received from the product evaporators 11.

In the operation of this system for condensing citrus fruit juices such as orange juice, it is contemplated that ammonia, if used as the refrigerant, will be compressed to about 205 lbs. gauge pressure with a superheat which may attain 180° F. The sensible heat in the gas will be utilized but most of the evaporation is performed by the latent heat of liquefaction of the gas. The refrigerant will condense at about 102° F. and emerge from the evaporator at about 102° F. Even though the cooling water available near an orange juice extraction plant may be as high as 80° F., it will be entirely practical to cool the refrigerant from 102° F. down to about 85° F. in the condenser 42 and cooler 43.

The degree of cooling of the refrigerant and the total heat removed therefrom at this point is a matter for regulation in order to maintain uniform operating pressures and temperatures in the system. This control and an alternative control for the same general purpose will be described hereinafter.

Before bringing the liquid refrigerant into heat-exchange with the water vapors which are to be condensed, the refrigerant is chilled below the temperature of the vapor. While the refrigerant condensed in the evaporators could be wholly cooled by flash evaporation to a temperature below the water vapor temperature, it is more economical to partially cool the liquid refrigerant in the heat exchangers 42, 43. In the process contemplated the juices will be evaporated at about 60° F., and in order to attain an adequate temperature differential in the condenser 35 between the water vapor and the liquid refrigerant the latter is cooled to about 50° F., by flashing off some of the liquid into the suction side of the line. By maintaining the compressor suction pressure at about 75 pounds gauge pressure the refrigerant will vaporize in the condenser at about 50° F.

Vaporized refrigerant will then be withdrawn from the space in the condenser above the upper end of the tubes through a pipe 51 into the receiver 48 and thence through a pipe 52 into a compressor 53 of any suitable construction from which it is then delivered to the pipe 17 for recirculation again through the evaporators.

Thus, briefly, the latent heat of vaporization of the refrigerant is supplied by the water vapor, thus condensing the latter, while the sensible heat and latent heat of liquefaction of the refrigerant is transferred to the juices in the evaporator to boil the water therefrom. Through the use of a suitable ejector and a condensate pump and an evacuator pump for the concentrated juice the high vacuum produced principally by the condensation of the water vapor, can be maintained in the evaporator and the condenser. It is found that a vacuum of about 28 to 29½ inches of mercury may be maintained easily.

In a system such as is here described orange juice may be evaporated from an initial average density of about 11 Brix to about 44 Brix. It is contemplated that the concentrated juice may immediately thereafter be frozen or kept at a very low temperature and reconstituted later into a solution of normal density at which time it will be found to retain substantially all of its initial qualities both as to food value and flavor.

As an aid to the maintenance of natural flavor, it has been found desirable to concentrate the fruit juice, or particularly orange juice, to about 55 Brix, discharge it from the evaporator to a tank under atmospheric pressure, and before freezing it, dilute it with sufficient fresh orange juice to lower the density to about 44 Brix. The introduction of this proportion of fresh juice is found to impart a sufficient natural flavor to the entire body of concentrate. Subsequent freezing of the concentrated product, thus produced, does not at all impair the flavor.

It is obvious that the preservation of citrus fruit juices in this condensed form offers many advantages from the standpoint of storage and shipping costs.

The invention is not limited to the concentration of citrus fruit juices, but embraces the evaporation of other aqueous solutions, which may be advantageously concentrated in this manner.

Orange juice, as it comes from the presses, is preferably heated to kill enzymes or other constituents that might interfere with its preservation. As it also contains considerable air it is preferred to introduce it through pipe 54 into a deaerator 55, and allow it to flow downwardly in a thin film over a spiral channel 56 and then fall into the bottom of tank 55 from which it will be withdrawn by pipe 34. A vacuum pump 57 of any suitable construction will evacuate the air from the film of juice flowing over channel 56. Thus foaming of the juice in the evaporators will be prevented and counter pressures due to excess air in the water vapor space in condenser 35 will be avoided.

It will be assumed that the usual accessories such as valves, pressure gauges and thermometers will be supplied throughout the apparatus so that uniformity of desirable operating conditions may be observed and regulated.

It is contemplated that the evaporation methods and apparatus herein described will be operated on a continuous basis, and to be used successfully the operation should proceed without substantial variation in the temperatures and pressures maintained in various parts of the system. Heat exchange with variable temperatures in the surrounding atmosphere, and variations in the constituents of the liquid, such as orange juice, undergoing concentration will tend to alter the operating temperatures and pressures.

The amount of refrigerant which must be evaporated per hour in the water vapor condenser, under constant load conditions, is such that this same quantity of refrigerant will contain more total heat when it passes through the juice evaporators than is required for production of the predetermined water vapor load. This excess heat will be due largely to the heat of compression of the refrigerant. Unless this excess heat is constantly eliminated from the system the compressor output pressure will continuously rise and disrupt the operation of the system.

Accordingly for controlling the system to make it operate uniformly there is provided two methods of control, and whichever heat elimination method control suits local plant conditions is employed.

In the vicinity of orange groves, if the water available for cooling is warmer than the water vapor the excess heat is eliminated by means of such cooling water flowing through the condenser 42 and liquid cooler 43. In this instance a pressure regulated valve 70 is installed, of any well known design, such as a diaphragm controlled valve, in the water intake pipe 71 leading to pump 44. A pipe 72, containing a fluid suitable for transmission of the regulating pressure, will connect this valve to the housing 73 which contains a diaphragm whose upper side is subject to pressure variations in the high pressure refrigerant gas line 15. Thus the rate of water flow, and hence heat discharge, will be controlled by the pressure of the compressed gas.

In the event that water available for cooling at the plant is colder than the water vapor temperature the other method for eliminating excess heat from the system may be used. In this latter instance the condenser shown in Figure 7 is installed and is connected to condenser 35 in place of the ejector 40 shown in Figure 1. The pipe 74 will be connected to the upper end of the water vapor space, in place of pipe 39 and will admit water vapor from condenser 35 into the condensing chamber 75. A housing 76 containing a diaphragm will be connected to the compressed gas line 17 and its diaphragm, subject to the pressure in the gas line, will transmit pressure variations through pipe 77 to a diaphragm controlled valve 78 positioned in the water supply line 79 which delivers water to the condenser 75. Water spilling over the weir 80 and falling down over the splash plates 81 will condense the water vapor and be discharged through a barometric leg 82. A high pressure steam jet 83 will eject non-condensable gases through ejector 84.

Pressure in the compressed gas line will determine and regulate the amount of water vapor condensed in this manner. The liquid refrigerant evaporating in the condenser 35 will therefore have a constant condensing load, less than the total vapor received from the evaporators by the amount condensed in condenser 75. The amount of refrigerant evaporated, compressed and delivered into the pipe 17 is thus regulated to produce enough compressed gas at the predetermined desired pressure to accomplish a uniform amount of evaporation per hour. The water vapor and refrigerant temperatures and pressures may thus be kept uniform. This method, of course, contemplates that pre-cooling of the refrigerant liquid before entry into condenser 35 will be accomplished, as heretofore explained by the flashing off to the suction side of the compressor of enough refrigerant to effect the desired pre-cooling.

If desired, a combination of the two foregoing methods of heat elimination could be utilized.

The juice evaporator units disclosed herein are claimed in co-pending Application No. 3,122 of 1949 (Serial No. 682,170) wherein substantially the same units are shown.

While there has been described a preferred manner of practicing the invention in detail as applied to the concentrating of orange juice it should be understood that the invention is not limited to such details or such materials, but is capable of considerable variation and modification.

In my co-pending Application No. 3,120/49 (Serial No. 686,376) I have described and claimed a continuous process for evaporating milk at a temperature of about 60° F., comprising compressing a refrigerant gas to a liquefaction pressure corresponding to a temperature far below 144° F. but higher than 60° F., utilizing the latent heat evolved when said compressed gas is liquefied for evaporating water from a continuous flow of milk through a heat exchanger, conducting the water vapour to a second heat exchanger, cooling the refrigerant liquefied in the first heat exchanger to a temperature lower than that of the water vapour evaporated from the milk, effecting heat exchange between said cooled refrigerant and said water vapour to vaporize the refrigerant and condense the water vapour thereby imposing a high vacuum on the milk being evaporated in the first heat exchanger; continuously discharging the condensed water vapour, continuously re-compressing the vaporized refrigerant and returning it to said first heat exchanger, and continuously discharging from the system controllably some of the heat that would otherwise be recycled with the refrigerant in order to maintain uniform operating temperatures and pressures on the refrigerant to permit a substantially constant compressor output pressure.

In my co-pending Application No. 3,121/49 (Serial No. 686,377) I have described and claimed a process for evaporating milk comprising compressing to a pressure a refrigerant gas which will thereby have a saturated temperature of about 160° F. at such pressure, utilizing said compressed refrigerant gas in an evaporator for evaporating water from the milk at a temperature of about 140° F., discharging from the system sufficient of the heat including heat of compression of the refrigerant, which otherwise would be recirculated in the refrigerant, for maintaining uniform operating conditions in the system, cooling the refrigerant to a temperature lower than the temperature of the water vapours derived from said evaporator, introducing the cool liquid refrigerant and water vapour into a condenser in heat exchanging relationship to evaporate the liquid refrigerant and simultaneously to condense the water vapour, discharging the condensed water vapour from the system, recompressing the refrigerant gas as before and reusing it in the same cycle, maintaining the water vapour space in the evaporator and condenser in communication with each other to thereby impress a high vacuum upon the milk, and continuously introducing fresh milk into the evaporator, and continuously evacuating concentrated milk therefrom.

What I claim is:—

1. A process for evaporating an aqueous solution under vacuum comprising effecting heat exchange between a compressed refrigerant gas and the solution to vaporize water from the solution and liquefy the gas, cooling the liquified refrigerant to a temperature lower than that of the water vapor evaporated from the solution, effecting heat exchange between the cooled refrigerant and the water vapor to vaporize the refrigerant and condense the water vapor thereby imposing a vacuum on the solution, recompressing the vaporized refrigerant for re-use in boiling further solution, and characterized by discharging continuously from the process sufficient of the heat which otherwise would be re-cycled in the refrigerant to maintain a substantially constant compressor output pressure.

2. A process according to Claim 1, wherein fresh solution is continuously added to the process for evaporation and concentrated solution is continuously discharged from the process.

3. A process according to Claim 1, wherein fresh solution is applied to the first of a series of successively connected evaporators, and the compressed refrigerant gas is supplied to each evaporator as a heating medium from a common source and is condensible at a temperature above a common predetermined evaporating temperature for the solution in all of said evaporators.

4. A process according to Claim 3, including recirculating the solution in each evaporator in a manner to provide a large surface area of solution in heat exchange relation with said medium maintained at substantially the same hydrostatic head as the vapor pressure thereon, continuously conducting a stream of partially concentrated solution from the first evaporator to the second in the series and recirculating it therein under the same conditions maintained in the first evaporator, continuously flowing a further concentrated stream from the second evaporator to the next evaporator and maintaining the same recirculating conditions therein, and from the last evaporator in the series continuously withdrawing a solution of the desired concentration.

5. A process according to Claim 1 or 4,

including flowing an aqueous solution under vacuum in film formation progressively over separated heat exchange surfaces while progressively increasing the concentration of the films, and evaporating the films by means of transfer thereto of the heat of liquefaction of the compressed refrigerant vapor supplied at the same pressure to all of said surfaces.

6. A process according to any of the preceding claims, in which the liquid refrigerant is first cooled by heat exchange with a cooling medium and then further cooled by flashing off a portion of the refrigerant to the suction side of the refrigerant cycle.

7. A process for concentrating orange juice comprising subjecting the juice to a vacuum to extract air therefrom and discharging the air, continuously introducing the de-aerated juice into the first series of vertical tubular evaporator units, recirculating a body of the juice repeatedly through the first unit in a manner to cause a downward film flow through each tube thereof, continuously diverting a stream of partially concentrated juice into the next unit and recirculating it therethrough in the same manner, repeating said diversion and recirculation in the remainder of said units until a desired concentration is attained in the last unit, continuously withdrawing concentrated juice from the last unit, supplying to the tube chest of each unit from a common supply source a compressed refrigerant gas maintained at such a uniform predetermined pressure that it condenses to a liquid in all the tube chests thereby heating and evaporating the juice flowing as a film through the tubes, conducting the water vapor from the juice to a condenser therefor, withdrawing from all of the evaporator units the condensed refrigerant and cooling it to a temperature less than that of the water vapor, vaporizing the cooled liquid refrigerant in said condenser in heat exchange relation with said vapor to condense the latter at a rate effective to impose a high vacuum on the vapor space in said evaporators, recompressing the vaporized refrigerant for return to said supply source, and continuously discharging from the system sufficient heat extracted from the refrigerant during said cooling of the refrigerant to facilitate uniform operation of the compressor.

8. A low temperature evaporation apparatus comprising a refrigerant gas compressor, means for introducing compressed refrigerant gas into an evaporator and means for withdrawing it therefrom in liquid state, means for cooling the liquid refrigerant to a temperature below that of the water vapor, means for continuously introducing a dilute solution into said evaporator and means for withdrawing a concentrated solution therefrom, a water vapor condenser having a condensing chamber communicating with the solution space in said evaporator, means for introducing the cooled liquid refrigerant into said water vapor condenser in heat exchanging relationship with the water vapor therein, means connecting the compressor with the refrigerant vapor space in said condenser, and means for regulatably discharging from the system sufficient heat to maintain a substantially constant compressor output pressure.

9. Apparatus according to Claim 8, including means for flowing the solution in film formation at successively higher concentrations over heat exchange surfaces of a plurality of evaporators, means for evacuating solution of a desired concentration from the evaporator, means for partially cooling the condensed refrigerant, and additional means for further cooling the condensed refrigerant to lower than water vapor temperature, said partial cooling means including said means for discharging from the system sufficient heat to maintain uniform operating conditions in the apparatus.

10. An apparatus according to Claim 9, having means for conducting the unvaporized solution from the bottom of each evaporator to the next succeeding evaporator for circulation through the tubes thereof and from the last evaporator in the series to a point of discharge.

11. A process for evaporating a heat-sensitive water-containing solution, substantially as herein described with reference to the accompanying drawings.

12. A low temperature evaporation apparatus constructed and adapted to operate substantially as herein described with reference to the accompanying drawings.

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Chartered Patent Agents,
Agents for the Applicant.

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3 SHEETS
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SHEET 1

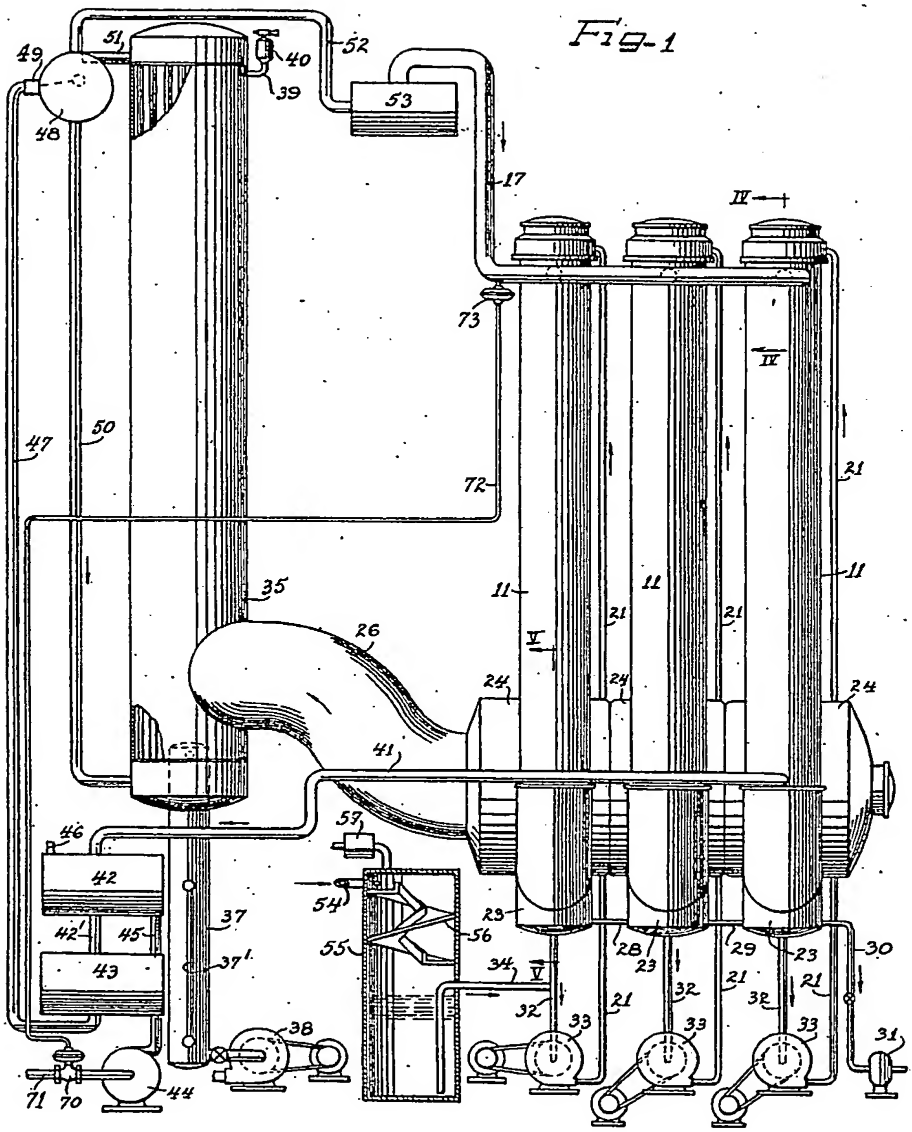


Fig-2

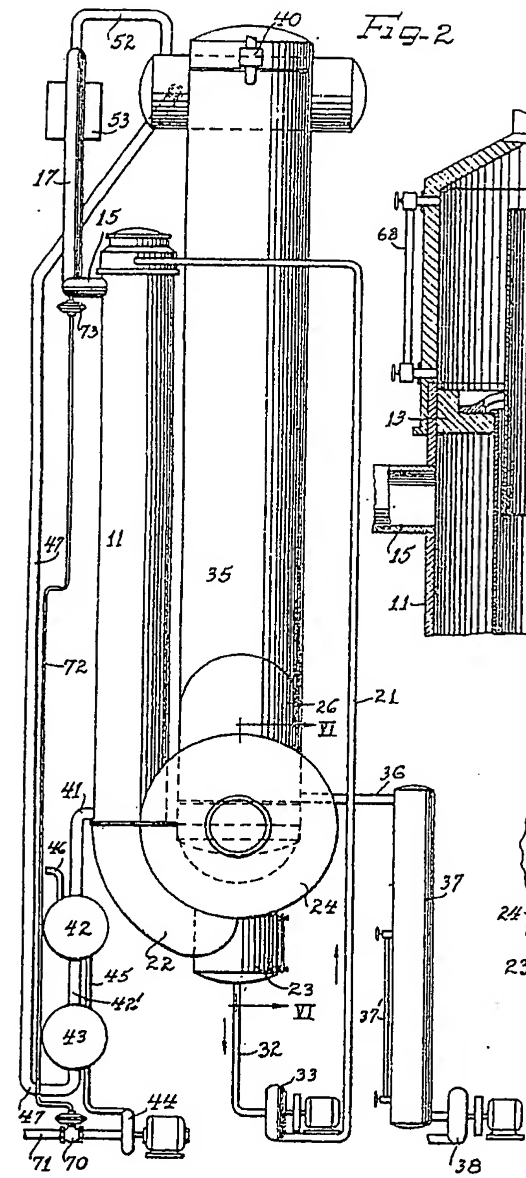


Fig-4

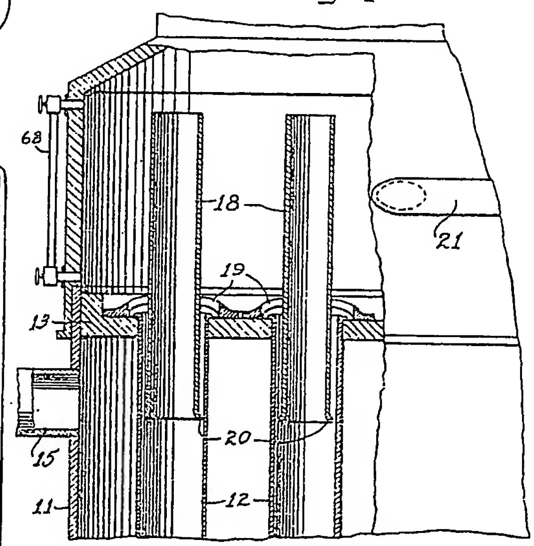
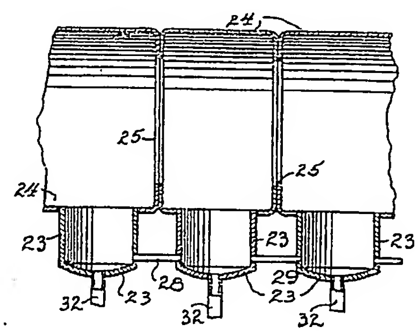


Fig-6



686,375 COMPLETE SPECIFICATION

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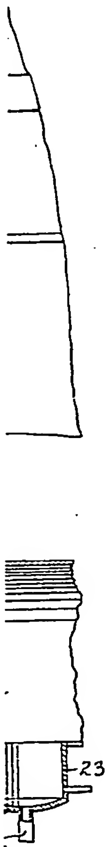
SHEETS 2 & 3



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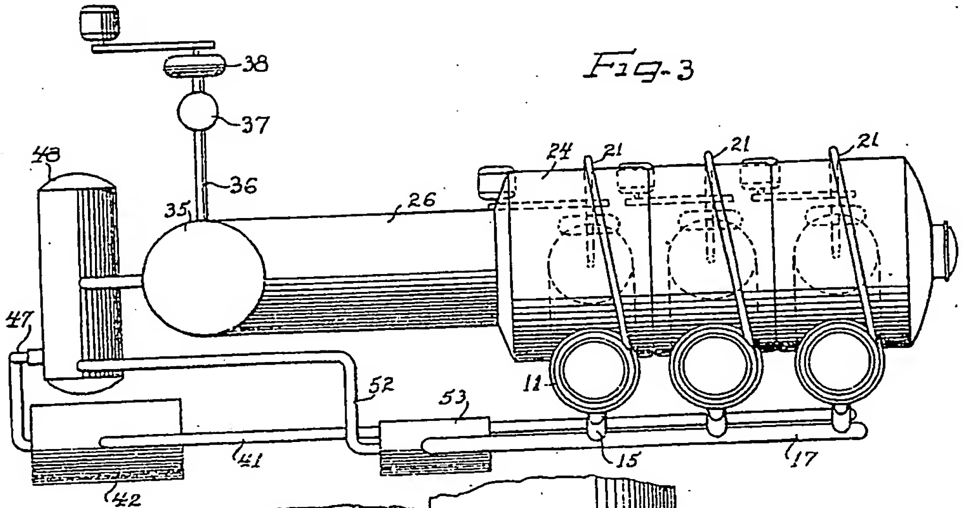


Fig-5

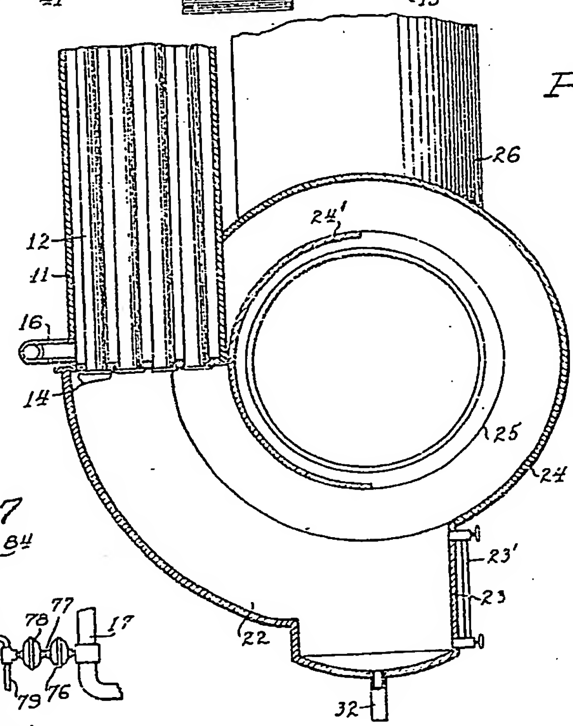
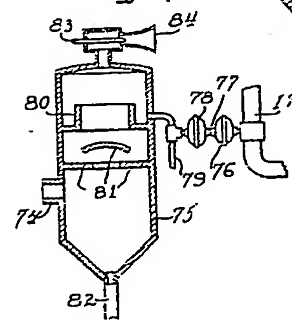


Fig-7



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3 SHEETS

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SHEETS 2 & 3

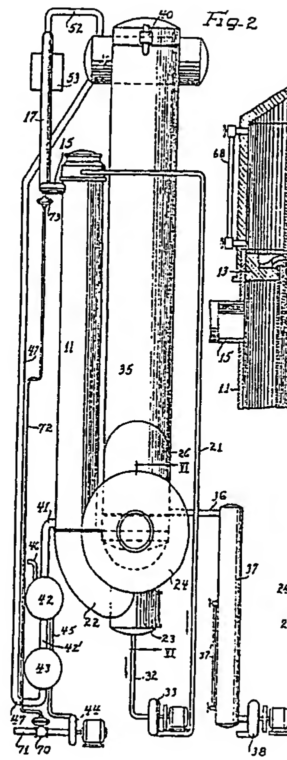

Fig-2

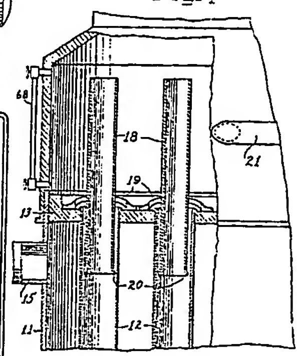

Fig-4

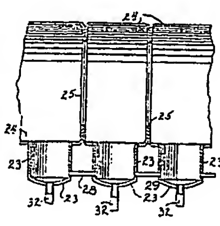

Fig-6

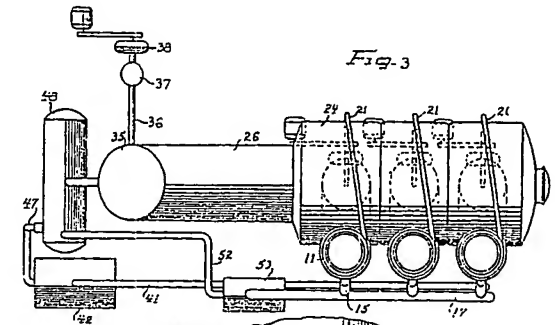

Fig-3

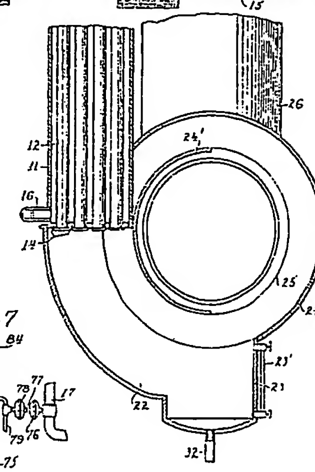

Fig-5

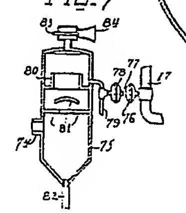

Fig-7

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